The PMT Test Facility in Lecce: Measurement Results of the First Phase Program

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Abstract

A new test facility has been built in the Lecce INFN and Physics Department Astroparticle Laboratory in order to test and select the Photomultiplier Tubes (PMTs) useful for the surface detectors of Auger (Next) as well as for extension of Auger South.
This note presents a description of the test facility and a preliminary measurement program performed using a Photonis XP1805 PMT.

1 Introduction

The Pierre Auger Observatory (PAO) was designed and built in order to study the cosmic rays at very high energy. Measurements of the arrival direction distribution, primary mass composition and energy spectra are the focusing key features in order to address all the opened questions regarding the energy range of interest. This range starts at $\approx 10^{18}$ eV and extents to primary energies of around 10^{20} eV. At these energies, the flux of cosmic rays gets very low, below 1 *particle per km*^{2} *per year*, and it is not possible to observe the primary particles directly but through the extensive air showers (EAS) produced by their interactions with the earth atmosphere. PAO was designed to study the EAS and an important characteristic of the experiment consists in the fact that two complementary air-shower techniques are implemented. This is known as *hybrid* concept and consists of a combination of a large surface array detectors, to measure particle at ground level, together with fluorescence detectors, to measure the development of air shower in the atmosphere above the array.

The Auger South consists of one site of 3,000 km^2, located near the city of Malargue, Argentina. The surface detector (SD) comprises over 1,600 water Cherenkov detectors placed on a triangular grid with 1.5 km spacing. On the periphery of the surface array are located four buidings each housing six telescope for fluorescence detection. The costruction of the South Observatory has been completed in 2008.
Extensions of the Auger experiment will profit of continuous test study and optimization of PMT. In Auger, the Cherenkov light is detected by three 9" PMTs (XP1805 from Photonis). On March 2009 Photonis announced the end of photomultiplier production, therefore the need to select a new PMT from other companies. Moreover, more extensive studies to ensure good response, calibration and triggering properties need to be performed in order to minimize the possible failures in a configuration where only one PMT can be employed. In this case, where only one PMT is used, the failure will traslate into the loss of one detector of the surface array with a direct consequence for the physics performance.

2 Experimental Setup

The measurement program follows the performance specifications required for the Auger experiment. The PMTs need to have a large dynamic range, a good linearity, a low counting rate and a low breakdown voltage. In order to check these parameters we setup a test facility in the Astroparticle Lecce Laboratory. Fig. 1 shows the schematic view of this setup and of the data acquisition system. The dark box (70x70x70 cm^3) hosts one PMT at a time. The detector under test can be positioned looking towards the box roof where a light source is positioned. Dark tight connectors plate for signals transmission and power is on the box panel.
We have characterized a PHOTONIS PMT (XP1805) instrumented with one of the bases designed for the Auger experiment that is powered up by a custom made DC-DC HV power supply.
The light source we used to perform the measurements consists of a LED Pulser controlled through a National Instruments USB-2659 Board connected to the data acquisition computer. The board has 48 digital I/O used for trigger generation, 4 digital analog converter (DAC) with 16 bit resolution and 2.8 MS/s with $I_{MAX} = 5$ mA/DAC. The DAC are used for LED pulse amplitude control. The board is also connected to the DC-DC power supply in order to control and monitor remotely the HV set on the PMT.
A blue LED (470 nm, 45 deg viewing angle) is used and in order to have fast turn-on turn-off response (short pulses) an appropriate LED driver has been designed (see Fig. 2). The LED driver discharges quickly a charge stored on a reference capacitance. This charge is proportional to the number of the photon generated by the Led. As we can see from Fig. 1, the LED is positioned in the center of a small box housing the driver. This box is mounted on a mechanical

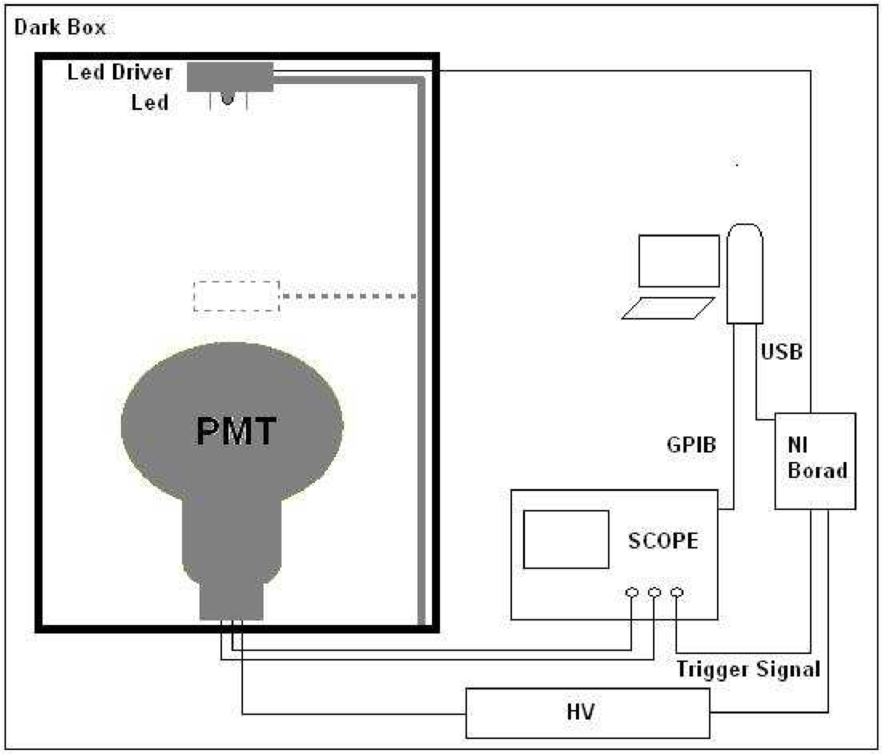

Figure 1: Schematic view of the experimental setup.

bracket that allows to put the LED at different positions respect to the PMT for non-linearity measurements (see Sec. 6).
The signals from anode and dynode are sent to a digital oscilloscope of 4 GSa/s sampling and 1 GHz bandwith (AGILENT MSO6104A) connected to the computer through GPIB. The data acquisition user interface is written in LabVIEW [1]. Using this graphical interface, it is possible to set the HV on the PMT, the LED voltage and the oscilloscope channels, moreover all the information from the run are saved on a ascii file: this includes waveforms from dynode and anode, the events number, and all the set parameters. The offline data analysis is performed using the ROOT analysis framework: ad hoc MACROS have been developed for peak finding, charge calculation, and spectra. Fig. 3 shows the ROOT histogram of a dynode signal acquired with the system set to perform single photoelectron measurements.

3 Dark Pulse Rate

The dark pulse rate is defined by the number of signals that are above a certain threshold when no light is incident on the photocathode. When a PMT is

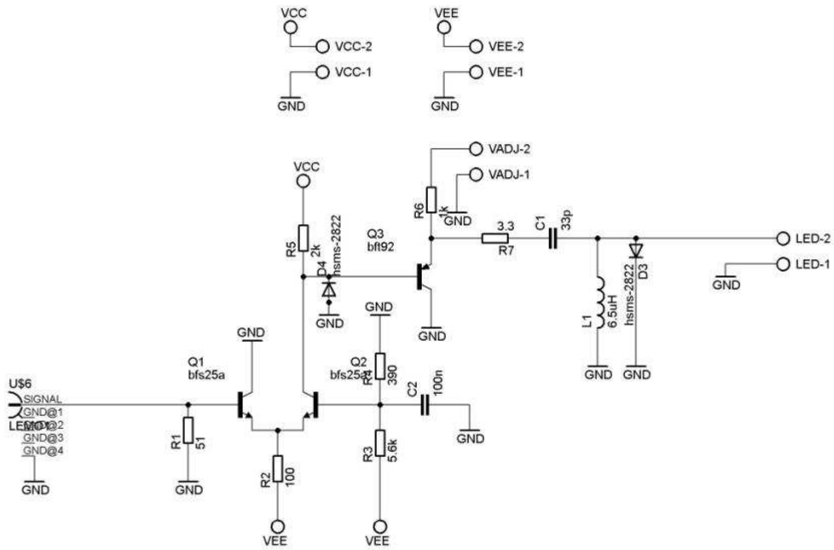

Figure 2: Schematic view of led driver.

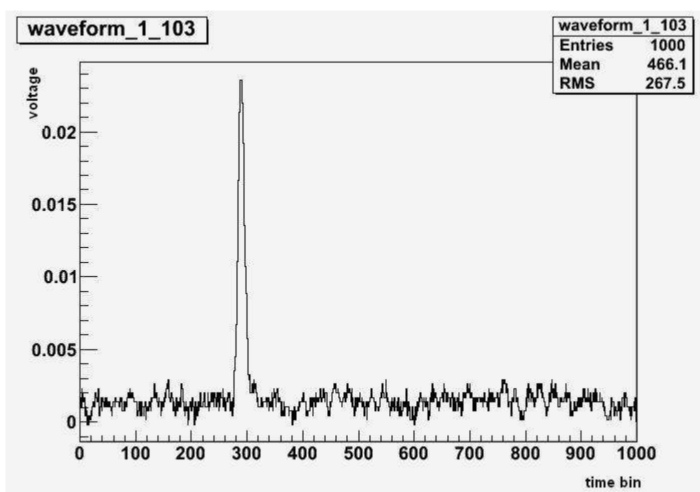

Figure 3: Single photoelectron dynode signal.

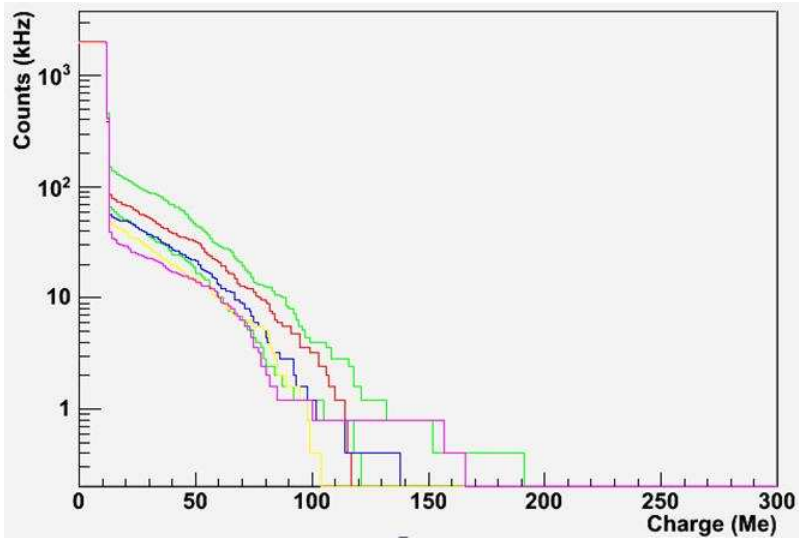

Figure 4: Signal counts rate as a function of the threshold for the first 30 min of data taking. Different color curves corripond to the 6 measurements performed in 30 min.

exposed to the light, if it is turned on it takes a certain time for recovering from the effect of the dark current. This current is caused mainly by the leakage current and thermoionic emission.
To get the dark pulse rate we perform a 2 hours measurement triggering on the noise and calculating the events fraction as a function of the threshold (divided by the time window). Fig. 4 shows the counts rate Vs the threshold (in Me) for the first 30 min of data taking. From this plot, once known the single photoelectron charge (see Sec. 4), we can calculate the event fraction at 1/4 of this spe charge that is the value took as reference from the Auger community [2]. The results of the measurement are shown in Fig. 5. It can be seen that after 2 hours, the rate of the dark pulse is below 10 KHz, that is in agreement with the Auger PMT requirements.

4 Single Photoelectron Spectrum

An important characterization of a PMT is the gain curve respect to the applied HV.
In order to get the absolute gain of the phototube at a certain voltage, the single photoeletron spectrum is measured. This measurement is performed setting the PMT to a gain of $\sim 2{\times}10^6$, according to the specifications given by the PHOTONIS and setting the LED in order to get signal on the first dynode only 10% of the time. In fact, the photoelectron emission process from the chatode follows the Poisson statistic, therefore the absence of photoelectrons 90% of the

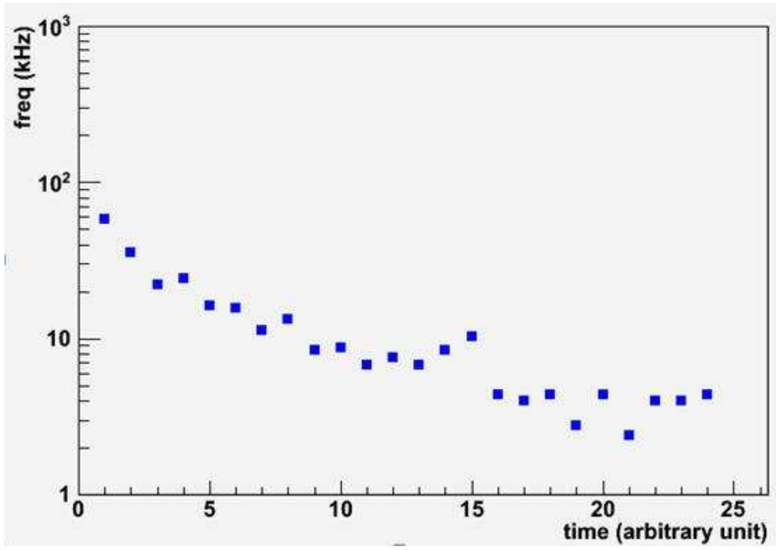

Figure 5: Dark pulse rate vs time spent in the dark box at 1/4 pe threshold.

time ensure a very low contamination of event having 2 or more photoelectrons. To avoid unexpected instability effects due to low powering, the LED was flashed at high intensity. The single photoelectron condition was reached using optical filters characterized by different transmittance. A series of preliminary measurements were performed at a fixed LED voltage (V_{LED}= 5.85 V) and using different optical filters. The SPE condition was reached using an F30 filter with 0.01 % trasmittance. Fig. 6 shows the SPE spectrum for the PMT under test. The first peak is the pedestal and the second peak is due to 1 photoelectron events. From this measurements we infer for HV = 1450 V a gain G = 0.63×10^6 in agreement with the data-sheet.

5 Gain vs Voltage

In the previous section we calculated the absolute gain at the voltage applied for SPE. To get the gain as a function of voltage, the LED intensity has been fixed and the PMT HV has been varied. The relationship between gain and input voltage is described by:

$$G = kV^{\beta} \quad (1)$$

$$logG = \gamma + \beta logV \quad (2)$$

with γ and β to be determined from measurements.
In Fig. 7 we reported the measurements performed for two different value of

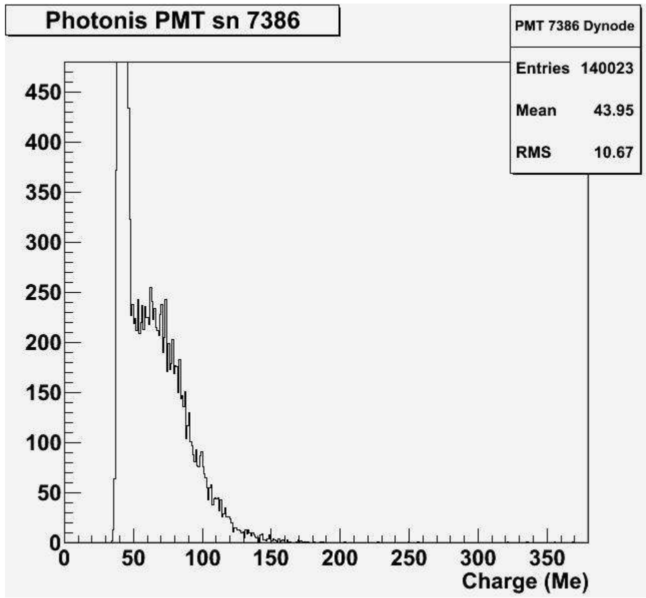

Figure 6: Single photoelectron spectrum for PHOTONIS PMT SN 7386.

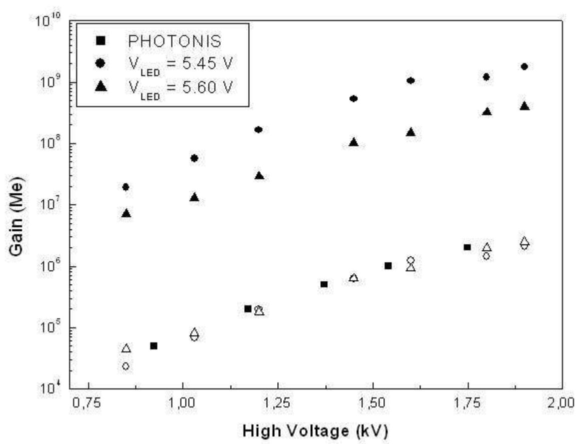

Figure 7: Gain curve as a function of voltage for the tested PMT. Mesurements were performed for two different values of the LED voltage (filled dots). The calibration results (open dots) are comapred with the measurement performed by PHOTONIS.

the LED voltage, 5.45 V and 5.60 V (filled dots); no filters have been used. The calibration and normalization is done applying the following formula:

$$G = \frac{(Q - Q_{ped})}{(Q - Q_{ped})_{SPE}} \times G_{SPE} \tag{3}$$

In Fig. 7, the results (open dots) are shown togheter with the measurement performed by Photonis.
For this PMT, the measured fit parameters are $\gamma = 3.189$ and $\beta = 1{,}7251$.

6 Non-Linearity Measurements

As we mentioned in Sec. 1, one of the most serious concern is the necessity of having PMTs which have a linear response over a large dynamic range. In fact, the calibration of each SD station is done using single muons which are constantly passing through it [3], while a cosmic ray air-shower consists of thousands of particles entering a given station.
The Auger SD PMTs must be operated at low gain ($\sim 2 \times 10^5$) in order not to saturate the digitizing electronics at the highest expected signals. At the same time, the PMT must be linear over a range extending from a few to about 10^5 photoelectrons [4]. The requirement is to have linearity within $\pm 5\%$ up to an anode current of 50 mA at the nominal gain.
In order to measure the linearity of the tested PMT we used the dual pulse method, which allows to avoid the need of a reference linear PMT or of a calibrated light source.
The LED was positioned in two different positions respect to the PMT (close and far). Acting on the LED biasing voltage, the light intensity was raised in order to reach the PMT saturation current at the closer position only.
The deviation from linearity is given by:

$$\eta = \frac{(I_C/I_F) - k}{k} \tag{4}$$

where I_C and I_F are the measured anode currents at the close and far position from the PMT and the constant k result from the fit to I_C/I_F performed at very low light level, before the onset of saturation effects.
From Fig.8, which shows the measured linearity η as a function of the currrent measured in the close position I_C, we can see that the tested PMT meets the non-linearity requirement.

7 Conclusion

The first phase of PMT tests at the Lecce facility has been concluded with the full characterization of the PHOTONIS XP1805. The main results have been summarized. The existing setup allows to plan test on different PMT as well as extensions of measurements program.

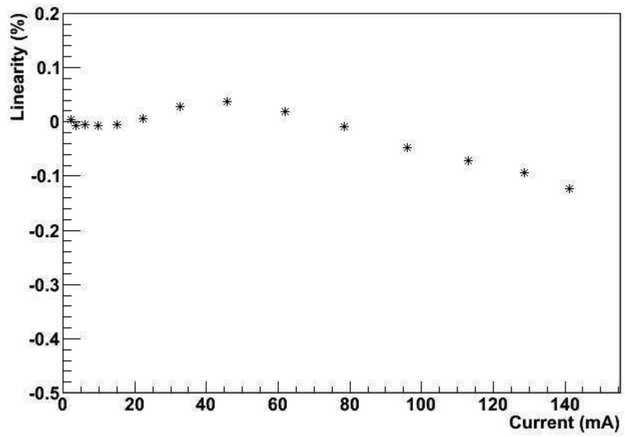

Figure 8: Linearity as a function of the anode current.

References

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